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The effects of enhanced Z penguins on lepton polarizations in $B \to X_s \ell^+ \ell^-$

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The sensitivity of the $B \to \pi K$ mode to electro-weak penguins and the recent experimental data for the $B \to \pi\pi, \pi K$ modes has given rise to what is known as the "$B \to \pi K$ puzzle". Recently it has been observed that this *puzzle* can be resolved by considering the new physics which can enter via Z^0 penguins. In this note we analyze the effect of this enhanced Z^0 penguins on the lepton polarization asymmetries of $b \to s\ell^+\ell^-$.

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Recent observations of the B-meson decay into two pseudo-scalar mesons have presented some significant deviations from the currently available theoretical predictions pointed out in [1] and recently reemphasized in [2, 3, 4, 5]. The decay into $\pi\pi$ channels can be reasonably well described with the theoretical framework of the effective Hamiltonian [5], although the naive factorization used in this context fails to describe the process and calculations involving non-factorizable contributions which had to be included to yield results in general agreement with data. Extensions of these results using $SU(3)$ symmetries for decays into πK channels, however, show considerable disagreement with experimental values. It has also been shown [5] that the results of decays into πK channels can be understood on the basis of an enhanced Z^0 penguin diagram together with a large phase. This may be the first indication of physics beyond the Standard Model (SM) since the phase of the accepted values of the CKM matrix cannot reproduce such a large phase in the Z^0 penguin diagram.

The possibility of strongly enhanced Z-penguin contributions was carried in relation to $K \to \pi\nu\bar{\nu}$ and $K \to \pi\ell\bar{\ell}$ decays for the first time in [6] and in [7] where constraints on these contributions imposed by the CP-violating ratio (ϵ'/ϵ) was investigated in a general class of SUSY models in [8]. The possibility of non-standard Z couplings in the context of $b \to s\bar{\ell}\ell$ transitions was studied in [9]. However, the authors of [5] were the first to relate possible enhancement of the Z-penguin to the non-leptonic decay modes involved in the"$B \to \pi K$" puzzle and were able to obtain definitive phenomenological values of the magnitude and phase of Z-penguins consistent with the $B \to \pi\pi, \pi K$ data. The estimates of the magnitude and phase of the Z^0 penguin required to fit the $\pi\pi$ and πK data, which have been made in [5], are purely on a phenomenological basis. On the theoretical side such an enhancement of the penguins can be accommodated within the supersymmetric extensions of the SM, the Minimal Supersymmetric Standard Model (MSSM) in particular. The flavour rotation of the squarks is different in such theories from the corresponding flavour rotation of the quarks, and this mismatch becomes the source of an additional phase in flavour changing amplitudes. Any attempts to fit the evaluated value of the Z^0 penguins with theory, however, is hopeless, since the parameters involved in estimating the resultant phase, which are essentially the off-diagonal elements of the squark mass matrix, are not known [10]. Irrespective of this the occurrence of a phase (other than the CKM phase) in the Z^0 penguin is a signal for a new source of CP-violation, and has wider implications.

The basic vertex involved in the analysis of [5] is the bsZ vertex. This vertex now having a phase beyond the CKM one, will result in CP-violation in semi-leptonic decays of the B-meson, such as $B \to X_s\ell^+\ell^-$. As is well known, due to the smallness of the coupling between b and u, the $b \to s\ell^+\ell^-$ amplitude effectively has an overall CKM phase. Therefore both in the SM and in supersymmetric extensions, with only the CKM phase, information regarding the phase cannot be extracted from any results involving this transition. As such we shall point out in this brief note that with an effectively complex bsZ^0 vertex the situation changes. In particular, we show that possible measurements of polarization asymmetries in the leptons, from the process $B \to X_s\ell^+\ell^-$, will provide a testing ground for the confirmation of the new phase and a measurement of the magnitude of the bsZ^0 vertex, as marked out in [5].

The effective Hamiltonian for the $b \to s$ transition can be written as

$$\mathcal{H}_{eff} \ = \ \frac{\alpha G_F}{\sqrt{2}\pi} V_{tb} V_{ts}^* \Big\{ C_9^{eff} \left(\bar{s}\gamma_\mu P_L b\right) \bar{\ell}\gamma^\mu \ell + C_{10} \left(\bar{s}\gamma_\mu P_L b\right)$$

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$$\times(\bar{\ell}\gamma^\mu\gamma^5\ell) - 2C_7^{eff}\bar{s}i\sigma_{\mu\nu}\frac{q^\nu}{q^2}m_bP_Rb(\bar{\ell}\gamma^\mu\ell)\Bigg\}. \tag{1}$$

where q is the momentum transferred to the lepton pair, given as $q = p_- + p_+$ (where p_- and p_+ are the momenta of leptons ℓ^- and ℓ^+ respectively), $V_{tb}V_{ts}^*$ are the CKM factors and $P_{L,R} = (1\mp\gamma_5)/2$. The Wilson coefficients C_i are evaluated at the electroweak scale and then evolved to the renormalization scale μ. For our analysis with the SM we choose a value for C_7^{eff} and C_{10} as:

$$C_7^{eff} = -0.315\ ,\ C_{10} = -4.642.$$

The coefficient C_9^{eff} is complex within the SM model and is a function of $\hat{s}$ $(= q^2/m_b^2)$ in next-to-leading order, where its value is given in [11, 12]:

$$C_9^{eff} = C_9(\mu) + Y(\mu,\hat{s}) \tag{2}$$

where $Y(\mu,\hat{s})$ has the one-loop contributions of the four quark operators, as given in [11]. C_9^{eff} also has a contribution from long distance effects associated with the real $c\bar{c}$ resonances, where these are taken care of by using the prescription given in [12, 13].

From the expression of the matrix element given in eqn.(1) we calculate the dilepton invariant mass distribution as:

$$\frac{d\Gamma}{d\hat{s}} = \frac{G_F m_b^5}{192\pi^3}\frac{\alpha^2}{4\pi^2}|V_{tb}V_{ts}^*|^2(1-\hat{s})^2\sqrt{1-\frac{4\hat{m_\ell}^2}{\hat{s}}}\,\triangle \tag{3}$$

where

$$\begin{aligned}\triangle &= 4\frac{(2+\hat{s})}{\hat{s}}\left(1+\frac{2\hat{m_\ell}^2}{\hat{s}}\right)|C_7^{eff}|^2 + (1+2\hat{s}) \\ &\quad \left(1+\frac{2\hat{m_\ell}^2}{\hat{s}}\right)|C_9^{eff}|^2 + \left(1-8\hat{m_\ell}^2+2\hat{s}+\frac{2\hat{m_\ell}^2}{\hat{s}}\right) \\ &\quad \times|C_{10}|^2 + 12\left(1+\frac{2\hat{m_\ell}^2}{\hat{s}}\right)Re(C_9^{eff*}C_7^{eff}).\end{aligned} \tag{4}$$

To define the polarized branching ratio and then the polarization asymmetries we will use the convention followed in earlier references, such as [13, 14]. For the evaluation of the polarized decay rates we introduce spin projection operators, defined as $N = (1+\gamma_5\not{S}_x)/2$ for ℓ^- and $M = (1+\gamma_5\not{W}_x)/2$ for ℓ^+, where $x = L, N, T$ correspond to the longitudinal, normal and transverse polarizations respectively. The orthogonal unit vectors S_x for ℓ^- and W_x for ℓ^+ in the rest frames of respective leptons are defined as:

$$\begin{aligned}S_L^\mu &\equiv (0,\mathbf{e_L}) = \left(0,\frac{\mathbf{p}_-}{|\mathbf{p}_-|}\right) \\ S_N^\mu &\equiv (0,\mathbf{e_N}) = \left(0,\frac{\mathbf{p_s}\times\mathbf{p}_-}{|\mathbf{p_s}\times\mathbf{p}_-|}\right) \\ S_T^\mu &\equiv (0,\mathbf{e_T}) = (0,\mathbf{e_N}\times\mathbf{e_L})\end{aligned} \tag{5}$$

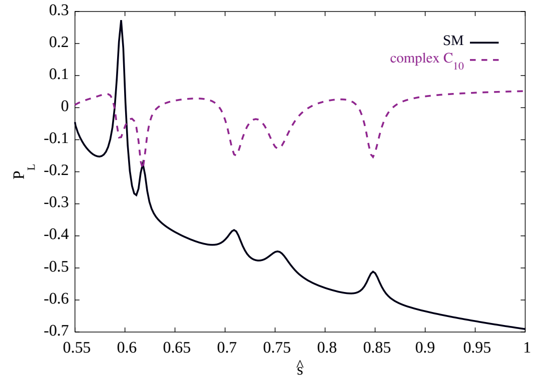

FIG. 1: Longitudinal polarization asymmetry $(\mathcal{P}_L^-)$ with dilepton invariant mass $(\hat{s})$

$$\begin{aligned}W_L^\mu &\equiv (0,\mathbf{w_L}) = \left(0,\frac{\mathbf{p}_+}{|\mathbf{p}_+|}\right) \\ W_N^\mu &\equiv (0,\mathbf{w_N}) = \left(\mathbf{0},\frac{\mathbf{p_s}\times\mathbf{p}_+}{|\mathbf{p_s}\times\mathbf{p}_+|}\right) \\ W_T^\mu &\equiv (0,\mathbf{w_t}) = (0,\mathbf{w_N}\times\mathbf{w_L})\end{aligned} \tag{6}$$

where $\mathbf{p}_-$, $\mathbf{p}_+$ and $\mathbf{p_s}$ are respectively the three momenta of ℓ^-, ℓ^+ and the s-quark in the dileptonic c.m. frame. Note that the above polarization vectors are defined in the rest frames of the leptons. We now boost these to the dileptonic c.m. frame. Only longitudinal vectors which lie along the boost will be boosted becoming:

$$\begin{aligned}S_L^\mu &= \left(\frac{|\mathbf{p}_-|}{m_\ell},\frac{E_\ell\mathbf{p}_-}{m_\ell|\mathbf{p}_-|}\right) \\ W_L^\mu &= \left(\frac{|\mathbf{p}_-|}{m_\ell},-\frac{E_\ell\mathbf{p}_-}{m_\ell|\mathbf{p}_-|}\right),\end{aligned} \tag{7}$$

where E_ℓ is the energy of either lepton (where both leptons have the same energy in the dileptonic c.m. frame).

The polarization asymmetries for ℓ^- are defined by the equation

$$\mathcal{P}_x^-(\hat{s}) = \frac{d\Gamma(\mathbf{n}=\mathbf{e_x})/d\hat{s} - d\Gamma(\mathbf{n}=-\mathbf{e_x})/d\hat{s}}{d\Gamma(\mathbf{n}=\mathbf{e_x})/d\hat{s} + d\Gamma(\mathbf{n}=-\mathbf{e_x})/d\hat{s}}. \tag{8}$$

$$\begin{aligned}\mathcal{P}_L^- &= \frac{2}{\triangle}\left(6Re[C_{10}^*C_7^{eff}] + (1+2\hat{s})\,Re[C_{10}^*C_9^{eff}]\right) \\ &\quad \times\sqrt{1-\frac{4\hat{m}_\ell^2}{\hat{s}}},\end{aligned} \tag{9}$$

$$\begin{aligned}\mathcal{P}_N^- &= \frac{3\pi\hat{m}_\ell}{2\sqrt{\hat{s}}\triangle}\left(Im[C_7^{eff}C_{10}^*] + Im[C_9^{eff}C_{10}^*]\hat{s}\right) \\ &\quad \times\sqrt{1-\frac{4\hat{m}_\ell}{\hat{s}}},\end{aligned} \tag{10}$$

$$\begin{aligned}\mathcal{P}_T^- &= \frac{3\pi\hat{m}_\ell}{2\sqrt{\hat{s}}\triangle}\left(-\frac{4}{\hat{s}}|C_7^{eff}|^2 - \hat{s}|C_9^{eff}| - 4Re[C_7^{eff}C_9^{eff}]\right. \\ &\quad \left. +2Re[C_7^{eff}C_{10}] + Re[C_9^{eff}C_{10}]\right)\end{aligned} \tag{11}$$

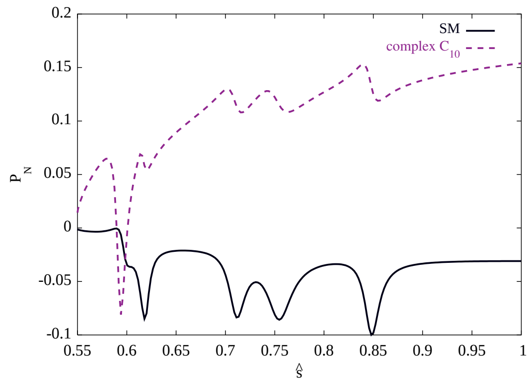

FIG. 2: Normal polarization asymmetry ($\mathcal{P}_N^-$) with dilepton invariant mass ($\hat{s}$)

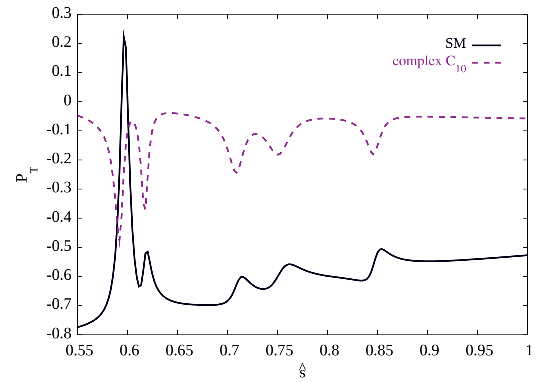

FIG. 3: Transverse polarization asymmetry ($\mathcal{P}_T^-$) with dilepton invariant mass ($\hat{s}$)

The corresponding asymmetries for ℓ^+ have expressions which are identical to those above (apart from an overall negative sign for $\mathcal{P}_L$ and $\mathcal{P}_N$), except for $\mathcal{P}_T$ where the sign of the last two terms is changed.

In order to fit the data for $B \to \pi K$ it was proposed that the Z^0 penguin has a large phase [5]. This fitting was modelled by Buras *et al.* which effectively makes the Wilson coefficient C_{10} a complex valued:

$$C_{10} = -(2.2/\sin^2\theta_w)e^{i\phi_{10}} \quad , \quad \phi_{10} = \left(\frac{103}{180}\pi\right), \tag{12}$$

which not only has a large phase but also a magnitude more then twice the SM expectation.

In figures (1)-(3) we show our results for the various polarization asymmetries both within the SM and for the enhanced value of the Z^0 penguin, as modelled in eqn.(12). As can be seen the results dramatically change with the new value of the coefficient C_{10}, as compared with the results obtained in the SM and the MSSM. Measurement of these polarization asymmetries would thus provide a direct test of the validity of the model in [5] for enhanced and complex values of the bsZ vertex. In table I we have given the averaged values of these asymmetries. The averaging procedure which we have adopted is:[1]

$$\langle \mathcal{P}_x \rangle = \frac{\displaystyle\int_{(3.646+0.02)^2/m_b^2}^{1} \mathcal{P}_x \times \frac{d\Gamma}{d\hat{s}} d\hat{s}}{\displaystyle\int_{(3.646+0.02)^2/m_b^2}^{1} \frac{d\Gamma}{d\hat{s}} d\hat{s}} \tag{13}$$

As can see from the graphs in figures (1)-(3) a complex value of the bsZ vertex gives the longitudinal and transverse polarizations a decreased value as compared to their SM values, however, the normal asymmetry shows a substantial increase from its respective SM value. This can also be seen from the averaged values of these asymmetries given in Table I. $\mathcal{P}_N$ not only changes its sign as compared to its SM value but also its magnitude increases by more than 100%.

It is clear that future measurements of the enhanced normal polarization asymmetry would be the more suitable testing ground for the validity of a complex bsZ vertex.

Model	BR $\times 10^7$	$\mathcal{P}_L^-$	$\mathcal{P}_N^-$	$\mathcal{P}_T^-$
SM	2.39	- 0.37	- 0.04	- 0.58
enhanced bsZ	6.12	-0.04	0.1	- 0.13

TABLE I: Predictions of the observables where BR is the branching ratio of $B \to X_s \tau^+\tau^-$

We would like to make a few further observations. The polarization asymmetries for ℓ^- in the CP conjugated process $\bar{b} \to \bar{s}\ell^-\ell^+$ can be obtained from eqns.(9)-(11) by conjugating all the weak phases whilst at the same time retaining the strong phases contained in C_9^{eff}. If we call the polarization asymmetry of ℓ^- in the conjugate process to be $\bar{\mathcal{P}}$ then in the SM we can derive several relations, such as $\mathcal{P}_L = \bar{\mathcal{P}}_L$ and $\mathcal{P}_N = \bar{\mathcal{P}}_N$; these types of relations are definitely violated if we have a large phase in C_{10}, which, as in eqn.(12), makes it dominantly imaginary.

Atwood and Hiller [15] have also recently obtained an effectively enhanced bsZ vertex. Their vertex includes a right handed coupling. The non-zero phase obtained in [5] is however quite rigid and a similar fit to the available data, where a right handed vertex also is included, has not been obtained.

For the decay $B \to X_d l^+ l^-$ the SM provides a relative phase between the various contributing terms, and a dominantly imaginary value of C_{10} would cause substantial interference between the CKM phases and the

[1] in the averaging we have integrated the observables over $\hat{s}$ in the region which is after the first charmonium resonance in the $b \to s\tau^+\tau^-$ process.

new bsZ phase. Our estimates of the polarization can easily be generalized to this case, however, this decay is expected to be much weaker than the one considered here and we do not present the results for this mode in this note.

Finally, the recently published data on CP asymmetries in the decay $B \to \phi K_s$ [16, 17] which has attracted a lot of theoretical attention [18], in particular that of Deshpande and Ghosh [19], where they have considered a model with extra down quarks and complex couplings, obtaining bounds on the effective complex coupling parameters of the Z-penguin graphs in the light of the data on $B \to \phi K_s$ [16, 17]. In the type of analysis that forms the basis of our polarization calculation, Buras *et al.*[5] have considered in detail the status of the effective penguin parameters obtained by them in relation to the data on CP asymmetries in $B \to \phi K_s$. The net result is that from the parameters obtained by them and used by us, a value of $\sin 2\beta$ in the decay $B \to \phi K_s$ of the order $+1$, may well be possible. The experimental data has large uncertainties with a value for this parameter given as [16, 17]

$$\mathrm{BaBar}: +0.45 \pm 0.43 \pm 0.07$$

and

$$\mathrm{Belle}: -0.96 \pm 0.50^{+0.09}_{-0.11}.$$

There is thus considerable disagreement between the average value of the results of these two groups and the theoretical result quoted above. However as observed in [5] the error bars are too large for any definitive conclusion to be made. The data of the two groups also has large differences. There are also theoretical possibilities specific to the transition $b \to ss\bar{s}$, such as a Higgs meditated amplitude in SUSY models with large $tan\beta$ (considered by Kane *et al.*[18]) making it difficult to assess definitively the disagreement between the predicted and the experimental result for $B \to \phi K_s$. The scenario will become clearer as more accurate experimental numbers become available. Our results on the possibilities of polarization results to study CP violation provide another parameter for comparison when such results become available.

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[1] A. J. Buras and R. Fleischer, Eur. Phys. J. C **16**, 97 (2000) [arXiv:hep-ph/0003323].

[2] T. Yoshikawa, Phys. Rev. D **68**, 054023 (2003) [arXiv:hep-ph/0306147].

[3] M. Gronau and J. L. Rosner, Phys. Lett. B **572**, 43 (2003) [arXiv:hep-ph/0307095].

[4] M. Beneke and M. Neubert, Nucl. Phys. B **675**, 333 (2003) [arXiv:hep-ph/0308039].

[5] A. J. Buras, R. Fleischer, S. Recksiegel and F. Schwab, to appear in *Phys. Rev. Lett.* [arXiv:hep-ph/0312259] . A. J. Buras, R. Fleischer, S. Recksiegel and F. Schwab, arXiv:hep-ph/0402112. A. J. Buras, R. Fleischer, S. Recksiegel and F. Schwab, Eur. Phys. J. C **32**, 45 (2003) [arXiv:hep-ph/0309012].

[6] G. Colangelo and G. Isidori, JHEP **9809**, 009 (1998) [arXiv:hep-ph/9808487];

[7] A. J. Buras and L. Silvestrini, Nucl. Phys. B **546**, 299 (1999) [arXiv:hep-ph/9811471].

[8] A. J. Buras, G. Colangelo, G. Isidori, A. Romanino and L. Silvestrini, Nucl. Phys. B **566**, 3 (2000) [arXiv:hep-ph/9908371].

[9] G. Buchalla, G. Hiller and G. Isidori, Phys. Rev. D **63**, 014015 (2001) [arXiv:hep-ph/0006136] ; G. Isidori, arXiv:hep-ph/0009024.

[10] E. Lunghi, A. Masiero, I. Scimemi and L. Silvestrini, Nucl. Phys. B **568**, 120 (2000) [arXiv:hep-ph/9906286].

[11] B. Grinstein, M. J. Savage and M. B. Wise, Nucl. Phys. B **319**, 271 (1989) ; A. J. Buras and M. Münz, Phys. Rev. D **52**, 186 (1995) [arXiv:hep-ph/9501281].

[12] A. Ali, T. Mannel and T. Morozumi, Phys. Lett. B **273**, 505 (1991); C. S. Lim, T. Morozumi and A. I. Sanda, Phys. Lett. B **218**, 343 (1989); N. G. Deshpande, J. Trampetic and K. Panose, Phys. Rev. D **39**, 1461 (1989); P. J. O'Donnell and H. K. Tung, Phys. Rev. D **43**, 2067 (1991) .

[13] F. Krüger and L. M. Sehgal, Phys. Lett. B **380**, 199 (1996), [arXiv:hep-ph/9603237] ; J. L. Hewett, Phys. Rev. D **53**, 4964 (1996), [arXiv:hep-ph/9506289]. S. Rai Choudhury, A. Gupta and N. Gaur, Phys. Rev. D **60**, 115004 (1999) [arXiv:hep-ph/9902355]. S. Fukae, C. S. Kim and T. Yoshikawa, Phys. Rev. D **61**, 074015 (2000) [arXiv:hep-ph/9908229].

[14] S. Rai Choudhury, N. Gaur and N. Mahajan, Phys. Rev. D **66**, 054003 (2002) [arXiv:hep-ph/0203041]. S. R. Choudhury and N. Gaur, arXiv:hep-ph/0205076. N. Gaur, arXiv:hep-ph/0305242.

[15] D. Atwood and G. Hiller, arXiv:hep-ph/0307251.

[16] K. Abe *et al.* [Belle Collaboration], Phys. Rev. Lett. **91**, 261602 (2003) [arXiv:hep-ex/0308035].

[17] T. E. Browder, Int. J. Mod. Phys. A **19**, 965 (2004) [arXiv:hep-ex/0312024].

[18] A. Kagan, arXiv:hep-ph/9806266. G. Hiller, Phys. Rev. D **66**, 071502 (2002) [arXiv:hep-ph/0207356]. A. Datta, Phys. Rev. D **66**, 071702 (2002) [arXiv:hep-ph/0208016]. M. Ciuchini and L. Silvestrini, Phys. Rev. Lett. **89**, 231802 (2002) [arXiv:hep-ph/0208087]. B. Dutta, C. S. Kim and S. Oh, Phys. Rev. Lett. **90**, 011801 (2003) [arXiv:hep-ph/0208226]. S. Khalil and E. Kou,

Phys. Rev. D **67**, 055009 (2003) [arXiv:hep-ph/0212023]. C. W. Chiang and J. L. Rosner, Phys. Rev. D **68**, 014007 (2003) [arXiv:hep-ph/0302094]. A. Kundu and T. Mitra, Phys. Rev. D **67**, 116005 (2003) [arXiv:hep-ph/0302123]. K. Agashe and C. D. Carone, Phys. Rev. D **68**, 035017 (2003) [arXiv:hep-ph/0304229]. G. L. Kane, P. Ko, H. b. Wang, C. Kolda, J. h. Park and L. T. Wang, Phys. Rev. Lett. **90**, 141803 (2003) [arXiv:hep-ph/0304239]. D. Chakraverty, E. Gabrielli, K. Huitu and S. Khalil, Phys. Rev. D **68**, 095004 (2003) [arXiv:hep-ph/0306076]. J. F. Cheng, C. S. Huang and X. h. Wu, Phys. Lett. B **585**, 287 (2004) [arXiv:hep-ph/0306086]. R. Arnowitt, B. Dutta and B. Hu, Phys. Rev. D **68**, 075008 (2003) [arXiv:hep-ph/0307152]. C. Dariescu, M. A. Dariescu, N. G. Deshpande and D. K. Ghosh, arXiv:hep-ph/0308305.

[19] N. G. Deshpande and D. K. Ghosh, arXiv:hep-ph/0311332.